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RESEARCH REPORT

AIR DEFENCE SYSTEMS AND WEAPONS

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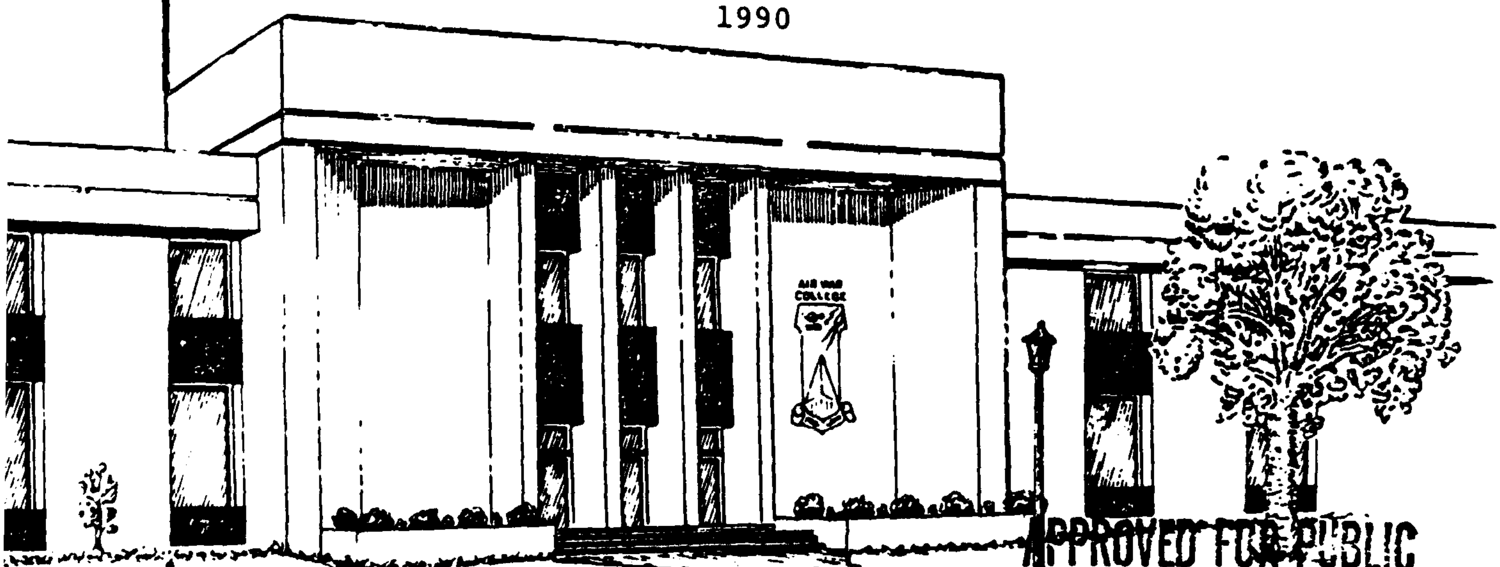

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AIR DEFENCE SYSTEMS AND WEAPONS

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A DEFENCE ANALYTICAL STUDY

SUBMITTED TO THE FACULTY

IN

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BIOGRAPHICAL SKETCH

Colonel Mohamed Al Rabi is a member of the Royal Saudi Air Force. He was born in Al Jouf, Saudi Arabia in 1944. After completing high school in 1963, he joined the RSAF and attended the King Abdulaziz Military College. In 1965 was selected for training in the United Kingdom (UK) as a Weapon Controller and Air Traffic Controller (ATC). Was commissioned as a 2Lt in 1966. In 1969 had advance training in Ground Controlled Interception (GCI) in the UK. In 1970 had advance training on Air Defence in Pakistan. Colonel Mohamed attended SOS in 1978, ACSC in 1982, and AWC in 1990, all were at Maxwell Air Force Base, Alabama. Colonel Mohamed has served as a senior Air Traffic Controller (SATCO) 1969 - 1971, at the Royal Saudi Air Force Headquarters, 1972 - 1975; Sector Operation Center Commander (SOC), 1976 - 1986; ACSC Instructor, 1987; the Technical Studies Institute Commander, 1988. Colonel Mohamed is married and has eight children. He likes swimming, open water diving, jogging, and playing soccer.

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CHAPTER I

1 - INTRODUCTION

Defence of a national air space is fundamental to every nations security, and at first sight, appears to require little more than the ability to accurately place intercepting fighter aircraft in a sufficient quantities to deal with aggressions. To achieve effectiveness in defence of air space however, requires far more in the way of resources than just fighter aircraft, surface-to-air missiles and other weapon systems. While it is certainly obvious that sensors such as radar systems are required to give adequate warning of attackers approaches. It is not always so readily apparent that these sensors and the associated weapon systems are interconnected to from a comprehensive system in order to attain a properly coordinated defensive entity. A chain of radar stations to is be positioned in a selected area to provide early warning of impending raids at maximum range and provide required information such as strength, heading, altitude, speed, and if possible, the aircraft types. The fighter controllers assess threats and dispatch defending aircraft to meet the target. The status of the defending squadrons is shown on the board, a key part of the system is the communication network. The basic concepts of an air defence system are to detect, locate, and identify intruders into the defended air space, a means of allocating defence resources to the best effect and methods to control these defending forces.

Many air defence systems are also linked to civil air traffic control nets, so that civil and military aircraft can be shown on a common display. It is increasingly likely that a nation updating its air defense system will integrate it with the civil ATC system from the outset, so that the system can operate in parallel. Modern radars are usually mobile in nature, if the sight is permanent then it will certainly be hardened against air attack although the static site is exceptionally vulnerable and prudence dictates that permanently sited systems are supplemented with sufficient mobiles to take their place in the event of loss or damage. Static sites are susceptible because their location can be accurately pinpointed by electronic means long before hostilities commence. For tactical and geographical reasons, some degree of mobility would seem to be almost essential. During wartime conditions, the movement of at least some components in a chain will provide protection, and in the event of losses of radar assets, the ability to rapidly redeploy those still existing may prove to be the only means of restoring adequate coverage. Also, changes in the nature of the threat would make mobility a desirable feature. Political and strategic considerations may bring out a requirement for radars to cover totally different sectors within the space of a decade or two. And weapons themselves, reflecting technological advances, vary in their characteristics within similar periods of time. Some twenty years ago the major threats were represented by ballistic missiles and manned aircraft, the latter mainly being operated at high altitudes. Now it is possible that at a low altitude, submarines or low level stealth aircraft launched cruise missile may represent the threat so that a nation previously vulnerable to over land attack may have to redeploy its defensive sensors to look seawards as well. Technological changes to and new modes of operation of weapon systems have demanded that similar progress be made in radar systems. Radars of 1960s and 70s vintage are no longer suited to todays threats such as the low flying attackers often operating beneath the terrain mask and possessing electronic counter measures designed specifically to defeat the means of detection.

CHAPTER II

1 - RADAR CAPABILITY

An aircraft operating within the ground clutter presents a far smaller target than the clutter itself. And although fixed clutter can be electronically removed through the use of techniques such as moving target indicator, temporary returns caused by heavy rain or by electronic counter-measures chaff are not so readily cancelled. Low altitude radars may also be affected by the echoes of surface vehicles, and so a combination of circumstances may result in a radar in a particular sector being over overwhelmed by signal returns which swamps the system.

A shrewd attacker can be expected to take all possible advantages of both natural and artificially created clutter. And the radars and their operators must be able to counter his actions. Advanced computer control of radar systems and signal processing now make use of range gated pulse doppler techniques, combined with wave form modification to track beams, which permits targets to be filtered out from their clutter environment.

Other techniques such as "burn-through" or the concentration of transmitted power on a specific sector, enhance a radar's performance against deliberate jamming or improve range in the sector. Sidelobe emission control can also improve jamming resistance, since to be at its most effective a jammer must be either within the main beam of a radar or within one of the main sidelobes. The use of electronically scanned antenna producing pencil beams rather than larger fan like beam spreads, likewise, improves jamming resistance. To protect the radars from attack due to their own radiation, may well prove a problem. Again, radar technology and todays anti-radiation missiles (ARM) would seem to pose an almost irresistible threat. Mobility of the system themselves is a useful first line of defence against the ARM through the denial of immediate targetting knowledge to a would be attacker. But mobility in it self is not sufficient in the longer term. The use of the lowest possible emitted power and geometrically thin beams, combined with low level sidelabe emissions provides additional protection.

Techniques such as variable emission strength or zero emission over certain sectors can also assist, together with the use of frequency agility, to make the capture of signals by an approaching ARM that much more difficult. Also, because an ARM will often depend on the arrival of an uninterrupted regular pulse stream from its target in order to provide guidance, pulse jitter and modification of pulse repetition frequency may also provide further means of defence. All of these emission-control techniques will provide varying degrees of protection. Another means of reducing vulnerability is the placement of strategically-sited decoy emitters within the area of the radar. By use of random transmissions, hostile electronic support measures can be denied their initial targeting of data and incoming missiles can be either confused or decoyed away from the radar proper by temporary shutdown of its transmission.

The use of shutdown and strict emission control is of course the ultimate protective measure, but it is not always practical. Its use should be as sparing as possible and other detection methods are being increasingly studied. In the forefront of these are electronic support measures which depend upon radar and radio transmissions of the hostile themselves to provide warning of approach. Here, however, the principles of emission control on the enemy's part will apply, and intelligent enemy will maintain radar or radio silence to the highest possible degree.

2 - NEW SENSORS

During the second World War, acoustic methods were tried as a means of detecting and locating approaching enemy aircraft, but these were not found to be very effective. Improved electronic processing has brought about some resurgence of these techniques which, over short range, may be effective only against slow-flying targets. In the day of the supersonic aircraft, to attempt to acoustically detect an enemy is a profitless exercise. Infrared detection methods, however, show signs of promise for short range defence. Aircraft engines produce appreciable thermal signature which can be detected, depending on prevailing atmospheric conditions. Incoming missiles, although the heat of their exhaust effluxes may be facing away from the detection system, still provide a detectable signature due to kinetic heating of their bodies caused by their passage through the air.

3 - COMMUNICATION NETWORK

The communications net that ties together the sensors and the control centers is now days far more complicated than the simple voice network of the past. In the majority of cases, radar information is passed directly to the points of command and control in digitized form for direct processing and display on commander's and battle staff screens. New communications techniques are employed extensively, and transmissions are likely to be packet-switched rather than message switched. Using packet-switching, data is routed in discrete quantities on packets of specified format and of cert in maximum size. Each packet comprises a header section containing the network address of the required destination, a data portion containing the information itself and a tail which contains checking and verification data.

The splitting of data into packages permits each of these to be independently routed over the network and packages may be sent via completely differing routes prior to re-assembly at the destination terminal. This makes the most effective use of the network and ensures the minimum delay in the transmission. Equally important in military terms, the existence of a package switched type of net automatically provides a degree of redundancy inherent in the system. Thus, there is an availability of alternative routes and should any link be lost, the system will continue to function, albeit at slightly reduced efficiency. The data networks are still backed by speech networks to allow voice conference between commanders and sensor sites. These act as a final fallback in the case of major emergency situations or to raise queries on the rare occasions when they cannot be readily resolved by data transmissions. While conventional landlines are still used for the network, it is becoming increasingly common for these to be substituted or supplemented by radio links which are not so vulnerable to hostile action. Sensibly, most networks use a mixture of at least triplicated landlines and radios communications facilities to provide the maximum redundancy and alternative routing availability for enhanced system survivability.

The use of data transmission is mainly due to the influence of the computer. Direct digital input of the vast amounts of data provided by modern sensors systems raises their effectiveness by orders of magnitude, and automation is an essential element of present day command and control techniques in the air defence context since no human commander could expect to filter, process and, appreciate the data quantities involved. Much of the data received, while of essential import to the system functions, is of a routine nature and does not necessarily need to be assimilated by the minds of the human controllers.

Computers enable this information to be processed and stoned,

and if required, displayed. But computers have the ability to automatically prioritize and to sift the data so that the relevant elements are presented for immediate attention.
It must be stressed however, that this dose not imply that the entire task is automatic. By letting the machines take care of the more mundane roles, the commander is free to concentrate on the more crucial decisions without concerning himself too much with the routine elements of control. Although systems are designed so that human controllers can interven· .t all stages if necessary, such is the complexity of a present generation air defence system that it is almost unthinkable that manual methods would have the required speed of reaction to deal with today's fast moving scenarios adequately. Computer assistance is thus essential. Communications with airfields, antiaircraft gun batteries, and surface-to-air missile·sites, like those between the sensors and commander centers must also be duplicated or triplicated to ensure survival of circuits and may well employ radio as well as landline links. Likewise, communications are equally well likely to be based on data transmission techniques as the mainstay of information transmission, although speech backup still remains. While communications with aircraft are of necessity, radio based and still mainly voice reliant, there is an increasing tendency for data transmission to be used for air ground air links, and the information transmission and distribution system of the 1990s and beyond will become more data dominate. The pilot of tomorrow will receive fewer

instructions by ear, it is more likely that targets will be indicated to him on a cockpit display complete with skirting vectors and missile launch data already precalculated and clearly presented with the minimum of voice instruction from the ground controllers. Voice transmissions will never be completely dispensed with for many reasons. Not only does it provide a fallback position for those occasions on which automated methods will not suffice in the event of system malfunction for example, but it also remains as the staple method of resolving problems over ambiguities with which automated means of information implementation cannot readily cope. It is impossible though, that speech, will be intelligible to unauthorized recipients, even if these should exist. Secure speech transmission will be assured through use of frequency-hopped transmission which are digitally encoded. Such changes in C3 technology symbolize how air defence networks have progressed, but there is a strong possibility that they will change to an even greater extent in the future. Ground based radars with their limited lines of sight are being supplemented (superseded) by airborne early warning systems which can extend the eyes of sensor networks to a degree unimaginable in the days of HF band radars. How much more could they be extended by the placement of radars and other sensors in spaceborne platforms? And it is possible that control of aircraft flying comparatively close to the earth's surface could be exercised more effectively from space itself. These considerations for the defence of sovereign air space and perhaps the void above this must be taken into account in the evolution of the next generation of air defense systems.

4 - ELECTRONIC COUNTER MEASURES

A major disadvantage of any radar, be it airborne, ship-based, or firmly on the ground, is the fact that any potential enemy can tune in to the transmitted emission, analyze it and then devise a way, either to confuse the receiver or blot out the signal altogether with high power electronic noise on the same frequency.

Two fundamental points must be stated however, their is no such thing as unjammable radar, and for every measure taken to improve a system, a counter will eventually be produced. ECM is a living science where changes can happen with bewildering speed and where the brightest of scientists live and work at the edge of advancing technology. Advances in electronics and particularly in applied computer techniques have meant a revolution in the approach to radar signal processing and the constant battle to out think the opposition. Suffice it to say that ECM is a big threat to the radar operator. Self-screening jamming pods are common place in modern aircraft inventories and specialist stand of ECM aircraft are the norm for any country contemplating a massed raid on defended territory.

However, the advent of very high powered processors has meant that techniques, like frequency hopping, very narrow beam widths, bi-static and multi-static radars, phased array and three-dimensional radars, have all become available to the planner in his attempts to remain one step ahead of the enemy.

5 - EARLY WARNING SYSTEM

Success in any air defence engagement depends, to a large extent, on the ability to detect an attacker as soon as possible. The defender must become aware of an impending attack in sufficient time to be able to alert his own forces, of whatever sort, in an attempt to neutralize the effects of surprise and to try to prevent the enemy concentrating his attack in time and space. Early warning is the generic phase that encompasses all the means of doing this. Early warning can be split into two distinct categories: ground based systems and airborne early warning. Of these two, the more diverse by far are the many detection systems that can be built at ground level.

6 - GROUND BASED WARNING SYSTEMS

Under normal circumstances, radar transmissions can be seen as analogous to light waves. They are sent out from the radar head and bounce back from any object in their path just as light waves would from a polished surface. Equally just like light, radar waves can be deflected, defused, or absorbed. The detected object having physical properties of its own which lead to a measurable level of radar reflexivity. This is usually called the radar cross-section. It is measured in square meters and is a useful means of comparing the likelihood of detection by radar of various air vehicles. At extremes of the scale an aircraft like a Boeing B-52 or a Tupulov "Bear" will have a very large radar cross-section where as a cruise missile or a carbon fibre drone will have a very small one. Another factor which affects radar reflectivity is aspect - the physical dimensions of a target which are presented to the radar. Take for instance an aircraft flying directly towards a radar head, the aspect presented to the radar will be fairly small. The leading edge of the wings, the cross-section of the fuselage, the engine nacelles, and the leading edge of the tail are probably all that will be seen. If the aircraft now turns through 90 degrees the radar can see the whole length of the fuselage, the slab section of the tail and the length, rather than the front of any under slung stores. Obviously, the second case will present a larger radar image to the receiver simply because there is more of the target for the radar waves to hit and reflect back. This is of course, a tremendous simplification. All sorts of things affect radar reflectivity: smooth or rough surfaces, angular constructions in the aircraft frame (known as corner reflectors), the type of paint used, reflections from the engine turbine blades or propellers, and such relatively small items as weapons carriage rails or missile pylons. By and large, however, it is the size and aspect of the target which makes the most impact.

There are also, as you would expect, a number of factors which affect operational efficiency of the radar system itself. To begin with, again just like light waves, radar transmissions at sea level cannot see beyond the horizon - the line of sight limit caused by the curvature of the earth. There are technical means of overcoming this. In this case, the only way to extend the horizon is to elevate the radar head. (Imagine you are standing on a beach looking out at the sea. As a ship steams away from you it will gradually disappear over the horizon. If you now race up to the top of a 100-foot high cliff and look again, the ship will one again be visible until, as before, it passes out of your line of sight. You can repeat this process climbing ever steeper cliffs until you are in effect, at heights normally associated with aircraft).

But there are self-evident physical constraints to the amount you can elevate a radar head. Obviously you will chose the highest point you can on which to site it, depending on the direction from which you think the threat will come. Equally, you can raise the radar aerial on a tower or plinth but the sheer size and weight of the system places severe limits on that process.

Size, in fact, is a major limitation for ground based radars. In general terms, the greater the power output and the larger the radar dish, the longer the range. Power obviously affects the strength of the outgoing radar a pulse (of electrical energy at a predetermined wavelength) and the size of the radar dish affects the amount of any returning reflections that can be collected. (Of course the bigger the radar dish is any small wind may knock it over, if they are heavy, cumbersome devices and because they are made to rotate or sway backwards and forwards, they need strong mounts and heavy-duty motors to drive them).

Long heavy rotating radars cannot be raised on very tall towers and are therefore very limited by the horizon in their low level cover. Of course if very high level cover is required, huge dishes can be used, pointing in fairly specific sectors, but it needs protection from wind and from heavy precipitation.

Another problem for ground based radars is mechanical reliability. This applies to any system, no matter how small or sophisticated, but for a large rotating scanner exposed to the elements, the problems are considerable. Motors that turn the head must be very powerful and operate within reasonably precise tolerances. Components such as bearings and turn tables must be both very strong and very durable. Environmental stresses can play havoc with concrete and steel structures and the effects of corrosion can be horrendous. So radars like these are bound to attract a large maintenance and man power bill although, on the other hand, they are relatively low-tech systems that can be understood and managed fairly easily. Primarily for that reason, many of the air defence radars built worldwide in the 1950s and 1960s are still operating today. But many have been replaced by 3D radars, etc.

7 - OVER THE HORIZON (OTHR)

Over the Horizon Radar (OTHR) uses the ionosphere as a mirror in the sky to bounce the transmitted radar signal off the upper atmosphere and to use the same path for the scattered signal that returns.

But OTHR is not without its problems. For a start it has no close in capability, it is designed to detect targets 1000-4000km from the site. This is fine for giving genuine early warning of activity and to help build up a picture of potential raid but it is too far away for an attempt at detailed control of the air battle. Equally, the gap between the 800-1000km minimum range and the point to be defended means that it has to be backed up by another system. There are problems, too, with propagation conditions. The degree to which radar waves are reflected is a function of the state of the ionosphere.

There are some influences like the day/night cycle, sun spot activity seasonal variations and high level winds which can all affect the performance of an OTHR system. Very complex processing is needed to unravel the faint returns and to ensure that erroneous multi-path responses are filtered out. But it can be done and the rewards and benefits are considerable; it covers huge tracks of land or sea there are no moving parts and maintenance is relatively easy it is not as susceptible to environmental factors as some other radars, and the cost of installation and operation is relatively cheap.

8 - HIGH FREQUENCY SURFACE WAVE RADAR

Another radar system designed to defeat the effects of the horizon is the high frequency surface wave radar (HFSWR). In this case a vertically polarized radar signal is transmitted at high power across a sea surface by using frequencies in the HF band. This surface wave can be made to stick to the curvature of the earth for ranges up to about 100N.M. The use of this phenomenon is somewhat limited by the fact that it works only over salt water, but it can produce good detection and tracking information to supplement other systems. It needs large transmit and receive sites and uses similar aerial arrays and processing techniques as sky wave radars.

9 - GROUND RADARS VULNERABILITY

Broadly, the dangers fall into three categories: vulnerability to ground attack; attack by aircraft, and vulnerability to ECM. Under normal circumstances, the position of an air defence radar is common knowledge to friends and foe alike. They are by definition, great big electronic beacon telling any one capable of interrogating the signal exactly where they are and what they do. If therefore, they are large fixed installations, vulnerability to attack is much greater. If, on the other hand, they are mobile sites that can be relocated to pre-prepared sites in time of war, particularly if you have enough of them to be able to switch transmissions from one site to another at the right moment, the vulnerability is much reduced.

10 - AIRBORNE EARLY WARNING (AEW)

Taking a radar set into the sky is not a new idea. (Almost as soon as the idea was operational on the ground in 1938, the scientists were trying to pierce the cover of the night and poor visibility by some means). The first production Boeing E-3A Airborne Warning and Control System (AWACS) was delivered to the UASF in March 1977 (and since then it has overcome most, if not all, of its inherent problems). Because of the size of the basic Boeing 707 air frame and its powerful engines, the radar and computer needs have been accommodated as have the requirements of the crew. Sufficient space is available to include the control aspect of the air defence battle so the aircraft comes much closer to a ground based radar in the sky. Using the most modern techniques, the radar can detect low flying targets over both land and sea and provide accurate tracking data on many targets simultaneously. But AWACS is reckoned to be very expensive and only a few nations can afford to operate a reasonably sized fleet of them.

11 - AEW VULNERABILITY

The big difficulty with AEW of any size, is that it requires a considerable amount of infrastructure, particularly in the form of avionics support. Good ground protection for some distance around a base is usually possible and ground-to-air weapons can be deployed to negate the airborne attacker. Once the AEW is airborne, the factors affecting vulnerability changes dramatically. Now we are in the realms of single type of threat-attack by another aircraft. Unless the AEW is put at exceptional risk by deliberately flying over or close to enemy held territory, and thus becoming a target for long range SAMs such as AS-5 or perhaps from an unmarked missile-armed ship, the only way to shot it down is to reach it with fighters.

CHAPTER III

1 - AIR DEFENCE AIRCRAFT

It is appropriate to consider the main "arm" of air defence, the AD fighter. The characteristics required of an AD fighter designed specifically for the air defence role maybe some what different to those of the more traditional "dog fighter." (The geographical disposition of the defending nation may determine the type of AD fighter such as, long range air defence patrols or and air defence interceptor and an air superiority fighters can be one of the same time, or you may have the need to combine weapons carrying capability powerful Al radars, good all-round performance and a long range tends to produce either a mix of fighter types or an emphases on the intercepter characteristics, such as range and loiter capability, quick reaction, agility, speed, avionics and radar and weapons systems). It is clear that for the air defence role, a fighter with good range is essential, it is obvious that defender needs to make the intercept as far away from the area to be defended as possible. Furthermore, it may well be necessary to chase the enemy for some distance either when he is inbound or outbound when trying to escape. In either case, the fighter may have to cover many miles on the pursuit. In a case of a Combat Air Patrol (CAP) it is important to remember that a CAP can be positioned anywhere from overhead to several hundred miles "up threat."

It is primarily the inherent range of an AD fighter that enables the defending planner to use the forward CAP option. The range and loiter time have a major impact on the design of a typical interceptor. It needs to be able to fly long distances without refueling at a reasonable speed so that it does not take too long to reach its patrol point. When it arrives, it needs to be able to throttle back to save fuel and maintain a suitable altitude to give it a fair chance of detecting the incoming attackers and starting the ensuing engagement with some advantage. Experience has shown that this altitude is about 15,000 - 20,000 ft., so the interceptor needs a combination of engines and wings that can produce good lift at such a height for low thrust output. Some designers have met this challenge by using variable geometry as with the Grumman F-14 and the Panavia Tornado F-3. Here the wings are partly swept back for cruise flight but are brought fully forward for the loiter phase. Other designs have used the delta wing such as the MIG-21 and the Mirage-2000. Other designs have concentrated on the all-round wing which combines swept wing characteristics with the advantages of the delta wing aircraft like the McDonald Douglas F-15. (Endurance, range, and speed tend to be closer together but the lift factor is so high that relatively low throttle settings from high power engines can be used. As with every other aspect of the air defence business, there is usually a compromise solution).

Another important factor is quick reaction, in any AD system the need for a quick reaction capability from ground alert is very important, specially if the warning time is very limited (and the ADGE system must be absolutely fool proof). Here, even a few seconds may make the difference between a successful intercept and a damaging blow. Fighters on ground alert must be able to scramble instantly, climb very quickly, sprint at very high speed to the intercept point, then engage the enemy immediately. They are in effect, manned long range multi-purpose missiles. With the pilot or crew already in the cockpit, it should take less than 60 seconds to start the engines and take off. Special alert pads can be built at the end of the runways with protection for the aircraft and crews. Engine systems can be designed for extra rapid starting and any ground safety devices, armament pins, and access panels for ground equipment must be kept to the minimum and be capable of fast removal.

2 - AGILITY AND SPEED

All fighter interceptors need to be agile. Agility will be the dominate factor to be able to destroy attacking aircraft which they may well be agile themselves such the F-18 and the F-16 class and therefore very agile indeed. The same is true for speed capability, very high speeds in the order of Mach 2 plus can give the interceptor some advantages, but only in a fairly narrow segment of the total combat arena. Most engagements are going to take place well below Mach 1.5 because few laden attack aircraft will be capable of speeds any greater than this. The exception to that are very fast (Mach 2.5 plus) reconnaissance USAF TR-1 and the SR-71. Another possibility is for the newer generation of large bombers, the USSR's TU-22m and TU-160 and the USAF Rockwell B-1B, B-2, and F-117, all of which should possess a Mach 2 plus capability at altitude and may combine this, eventually, with the ability to launch stand-off missiles at that speed.

3 - AVIONICS, RADAR, AND MISSILES

What makes the AD Fighter so special and maybe superior too? Is it the type of electronic systems and missiles it carries? The electronic systems that provide information to the crew, include the Al radar, the weapons aiming and control system and the HUD flight information and night navigation equipment. The radar of an AD interceptor is the eyes that enables this brand of combat aircraft to operate at night and in poor weather. (AD fighters listed as night, all weather (NAWX) fighters in fact as technical advantages in electronics have been made). The ability to operate at night and in all weather has been conferred on any aircraft with a radar and associated weapons system. What makes the Al radar special, and advances such as the new pulsed-doppler (PD) techniques and digital processing. Previously, weapon aiming information was generated by analogue computers which were low powered and simplistic. (This advance, coupled with the development of radar guided semi-active missiles such as the AIM 7 Sparrow). The ability to alter frequencies at random intervals, to vary the scan width and to perform altitude search by raising and lowering the scanner automatically, have all become commonplace.

One of the most significant of these advances has been the advent of medium pulse recurrence frequency (MPRF) radars.

It is the high-tech world of AI radar and data processing development that has made this possible and it is difficult to see where the limit may be.

The short range air-to-air missiles (SRAAM) seem much less complex undertakings. They are by and large, considerably smaller with, as their title indicates, less range and usually a smaller warhead. What they do have, however, is greater agility and usually the all important launch and leave capability.

Virtually all the SRAAM in production use an IR seeker head to home the missile onto the heat generated either by the target's engines or the surface friction caused by its passage through the air. The leading edge of wings and tail section in particular, become hot spots in relatively high speed flight.

The IR missile has been developed to a peak of sophistication that makes the very latest version like the Matra Magic 2 amazingly versatile weapons. The Magic 2 for example, is said to be able to maneuver at 50"g," be slaved to the aircraft's radar for better target acquisitions, have seeker head sensitivity several tens of times that of the early versions and to have a head-on kill capability. This capability, plus very high agility and a quick response system for indicating when target acquisition has occurred, makes missiles like this ideal for the high maneuvering, close combat situation.

There are very few air-to-air missiles designed to kill targets at ranges in excess of 40nm, the size of the rocket motor required leads to a heavy missile such as the Phoenix AIM-54A which entered service with the US Navy in 1974. This is quoted as having a range in excess of 110nm with an operating envelop of from sea level to heights above 80,000 ft. combined with the hughes AN/AWG-9 radar and fire control system installed in the F-14 Tomcat, this produces a formidable intercept system. Apart from its long range and high lethality, the Phoenix has another major characteristics which sets it apart from the other in-service missiles, MRAAM in that it has a genuine launch and leave capability. What this means is that once the missile has been launched it needs no further assistance from the fighter. These missiles confer an important advantage on the fire they can be used beyond visual range (BVR) the more common medium range air-to-air missiles (MRAAM) such as the British Aerospace Skyflash or the Matra Super 530 or the new USAF Hughes AIM 120 AMRAAM; all have this potential.

CHAPTER IV

1 - SURFACE TO AIR MISSILES (SAM)

The concept of air defence in depth should also include surface to air missiles, to be either a last ditch defensive system, or the best means of shooting down an attacker. It all depends on your point of view. Certainly, in the context of national air defence, it may seem risky to rely only on missiles to prevent the enemy from reaching his target. Even though each SAM is likely to be many times less expensive than each interceptor, it suffers from the major disadvantage that once in position around a target, or deployed in a belt across an enemy's likely line of advance, it becomes a fixed and consumable asset. Furthermore, if the enemy choses to attack another target, short range point defence SAMs of whatever sort are useless, whereas fighters may, at the very least, be able to chase the attacker on his escape from the target. This problem can be overcome to some extent by the belt system. If SAMs are deployed on a wide front with interconnecting arcs of fire, attackers can be confronted with a serious problem. Attackers must either route around the defences, if their fuel allows, or they must fight their way through---punching a gap in the defences to let the bulk of the attackers through. NATO uses the belt concept with the Nike and Patriot missiles, as do the Soviet with the SA-5. The problem with the "belt" however, is that if it is breached, the remaining prepositioned missiles may be useless. To use SAMs alone would thus mean covering every possible target area with enough missiles to take account of the enemy known strength. At this stage, the cost equation works against the missiles; so many would needed to give any degree of assurance that no nation could afford it.

Another important disadvantage of the surface-to-air missiles system is that it is relatively easy to develop a counter. The range of most systems deployed is soon an open secret because, if nothing else, experts can make accurate assumptions from the missiles dimensions. Stand-off air-launched weapons can then be used so that the attacking aircraft does not have to penetrate the missile engagement zone (MEZ). While it may be possible for the SAMs to engage the incoming missiles, the task is likely to be much more difficult. Even though SAM launchers can be reloaded, it can not be done swiftly enough to save the situation if the defences are out numbered. Swamping a MEZ with a coordinated combination of stand-off weapons and ECM to attack the SAMs guidance radars, is a very attractive option for the enemy. An effective SAM and AAAdefence should contain as many layers as can be provided, therefore, they are relatively a cheap and effective way of making life very difficult. Without them, the only solution is more fighter aircraft, it is all a question of a balance of investments.

CHAPTER V

1 - PU COMMAND AND CONTROL AND COMMUNICATIONS AND INTELLIGENCE (C3I)

A command and control system supporting a commander is not just a computer with its associated software and displays, it is not just communications links and, it is not even just all the information processing and fusion that must go into any well designed and well operating command and control system. It is all of the above and much more. The ideal command and control system supporting a commander is such that the commander knows what is going on, that he receives what is intended for him and that what he transmits is delivered to the intended addressee so that the command decisions are made with confidence and are based on information that is complete, true, and up-to-date. The purpose of a command and control system is, in the end, to provide assurance that orders are received as originally intended with follow-up in a timely fashion, which can make the difference between winning and losing wars.

The importance of command and control can be appreciated by considering the penalties for its failure. In a tactical engagement, failure in command and control may result in a tactical defeat, because a commander was unable to bring all his forces into action, or to apply them efficiently and effectively, or to prevent them from firing on each other. At the strategic level, failure in command and control may result in unnecessary escalation of hostilities. Tense international situations provide little margin for error in the application of force, so that extraordinary measures are often taken to make sure that command and control does not fail. The exercise of authority and direction by a properly designated commander over assigned forces is the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel equipment, communications facilities and procedures which are employed by a commander in planning, directing, coordinating and controlling forces and operations in the accomplishment of the mission.

Command and control is defined as the process employed by a commander in planning, directing, coordinating, and controlling forces operations in the accomplishment of the mission. The term command means the function to be performed, the word control means the information flow that permits a commander to assess the status and progress of his own forces analogous to friendly intelligence. The command and control process will be examined primarily from the perspective of decision making, where a commander, the decision maker is at a distance both from the phenomena on which he bases his decisions, and from the people whom he will task to execute them. His command and control process includes the methods that he uses to get those decisions carried out in setting up his command and control process. A commander at any echelon is likely to have three concerns; whether he has made adequate provisions so that he will be informed of significant events that affect his operations, whether he and his staff will be able to cope with the information received and to transform it into sensible and timely decisions and directives; and, whether the directives that reflect his decisions will be received and executed by subordinates in time to affect the outcome of the operation. These transitions from information to directives and from directives to action require decisions of three types: (1) operational decisions, (2) organizational decisions, and (3) information decisions. Commanders are expected to focus on operational decisions about the employment of their forces but such decisions are made in light of prior decisions of the two other types, organizational decisions and information decisions. A commander's organizational decisions establish a chain of command for the execution of his operational decision. They also establish a structure for the flow of orders and reports, as well as for the intermediate processing of information necessary to support his own decision making and to some extent, the decision making of his subordinate commanders. Information decisions are those decisions made by a commander as to what he believes to be and how that decision situation relates to the mission he is trying to accomplish. A commander's information decisions about what is happening, although often unrelated, necessarily precede his operational decisions about what actions he wants his subordinate commanders to take. Each commander then has a command and control process by which he makes information decisions (about the situation) and then makes operational decisions (about what action to be taken) and causes them to be executed all within a structure established by the organizational decisions made either by the commander or by some superior commander--Command is a human activity. The exercise of authority, one person over another, may be facilitated and in some cases may be made possible only by the application of technology, yet the command function never loses it's human dimensions; leadership, courage, and human judgement, are still as a reminder that function of command is a human activity. We read Clausewitz's description of "military genius" he elaborated on those aspects of intellect and strength of character that he feels distinguish the superior commanders; courage, determination, presence of mind, a sense of unity, and a power of judgement. Are these qualities enhanced or perhaps diminished by supporting C3 systems? Must C3 systems be mated to the commander's philosophical approach to command and control, augmenting his strengths and compensating for his weaknesses, or should commanders be required to adapt to standard systems. In command and war, Van Creveld uses the term "command systems" to mean the organization, technical means, and procedures used by a commander to exercise command. He points out that the basic command and control problem is as old as war itself.

2 - INFORMATION DECISIONS

A great portion of existing C3 systems are devoted to providing commanders with the information they need to assess the situation and indeed, the primary function of some commands is to provide such information. Yet the uncertainties are many, the information available is usually ambiguous, incomplete or conflicting, and often arrives late; often having been transmitted imperfectly, or received with error. Uncertainties about an event are usually reduced over time following the event as amplifying and clarifying reports are received and understood---but a commander usually needs to make up his mind about what action should be taken long before the situational uncertainties can be resolved completely. Command and control is a process that takes place within a structure that has many levels. At the higher levels, the policy consequences dominate, at the lower levels survival and effectiveness guide decision making. It is prudent for commanders at all levels to foresee possible situations so that they can think them through in order to create plans to deal with them. Problems that have no been thought about quite thoroughly in advance are not likely to be solved effectively during a rapidly evolving situation. Compatible experience and shared context enhance the likelihood of mind-to-mind communications between echelons. This whole process is facilitated when the several levels in the chain of command are provided with essentially identical portrayals of the action taking place so they are able to discuss with one another their assessment of the situation and possible courses of action. The shared understanding by sender and receiver about possible situations may be more important than computer-to-computer links in achievement of efficient and reliable time reporting. The extent to which fresh reports are fully understood is dependent on the amount of previous information exchanged. While a report is customarily viewed as transporting the information it contains, there may be more utility in thinking of a report as announcing which of the possible situations already recognized by both sender and receiver has now become operative. It should not be surprising to find that when a truly unexpected situation arises, a reporting system has to work much harder if it is to convey effectively, information that is indeed unanticipated. Two recent developments have significantly affected the command and control process. This first is that modern forces, employing stealth and high speeds, can be generated and applied over great distances in a matter of only a few hours, with strategic consequences. The second development is that super powers now have literally, worldwide surveillance coverage of potentially hostile forces activity. Taken together these developments place a great pressures on the developers of intelligence to deal with vast amounts of information and to do so rapidly. Surveillance data is converted into comprehensible forms and fused with other data at seat of government, then distributed to interested commanders in the field. This system is maturing and changing. The technology now facilitates greater tailoring of information for field commanders and use of the same raw data to develop both strategic and tactical intelligence is beginning to increase although it is not clear whether strategic analysts will always be able to recognize which data might have tactical significance for local commanders. There is also the risk that focusing on current intelligence may blind analysts to long term strategic indicators.

3 - ORGANIZATIONAL DECISIONS

Organizational decisions need to be made to establish where a commander gets his facts, whom he relies upon for advice, and how he insures that his operational decisions get executed, whether organizational decisions are made by the commander himself or by some superior commanders, such decisions:

> Support the making of information decisions by identifying the organizations to be tasked to obtain information and by structuring the flow of information to the commander.

> Support the making of operational decisions by structuring the flow of advice to the commander about what action to take and facilitate the execution of operational decisions by establishing a chain of command.

On the information flow side the objective is to tap what ever sources can provide the information needed to support sound decision making avoiding, if possible, being at the mercy of a single source for any particular kind of information with respect to advice about operational decisions. A commander might want to rely on a mix of advice from sources both internal (the commander's staff) and external (other commanders). On the execution side, on objective of organizational decisions is the achievement of "unity of effect," a formulation that leaves open the question as to which effects must be unified and avoids declaring whether unity of effort can be (or can only be) achieved by unity of command. Another objective may be to balance forces and tasks so that there is an equal strain on all parts. Organizational decisions create a command and control structure and establish "who decides what." Organizational decisions are central to command and control because they establish the structure of relationships that C3 systems are expected to interconnect. Organizational decisions also specify the roles that each commander is expected to fulfill in the command and control process. A separate and often overlooked implication of an organizational decision is that it narrows the command and control focus for each commander by specifying for him the immediate subordinate commanders to whom he will direct his orders. While the decisions of commanders at every echelon may be intended to affect operations at the scene of action, they should direct the action of commanders only at the next lower echelon. A chain of command establishes both the line of authority for getting the job done and the line of responsibility for success or failure.

In general, a command may be organized into divisions and subdivisions by one or more of the following methods:

By area (that is by grouping together all forces within an area from whatever services or nation or for whatever purpose).

By medium (that is, by grouping together ground forces, air forces, and seaborne forces).

By task (that is by grouping together all forces from whatever service that are directly involved in accomplishing the same task).

4 - OPERATIONAL DECISIONS

The technical and tactical competence of commanders is tested by the making of operational decisions. Many skills that are best developed by experience in command and in combat may need to be brought to bear, and a few of them are closely related to command and control.

Six Skills in Particular Come to Mind

The ability to communicate clearly, concisely and effectively and the willingness to rely on a minimum of directives.

The ability to visualize how subordinate and superior commanders are viewing the situation.

The ability to estimate how long it will take for decisions to be implemented, including how long it will be before subordinate commanders receive and understand changes in orders, and how long it will be before new orders start being executed.

The ability to estimate when reports ought to be received so that the failure of a report to arrive will raise the question as to whether or not the operation is proceeding as planned.

The ability to foresee how much disruption would be caused by a change in orders.

The ability to reduce confusion within friendly forces while promoting chaos in enemy forces so that there is less confusion on the friendly side than on the enemy side.

In the military planning process the classic logic for the making of operational decisions is the commanders estimate of the situation. The first steps of the estimate are the analysis of the mission and the identification of key considerations. The middle steps require identification of courses of action open to a commander and those open to his opponent. The final steps involve predicting outcomes of all possible interactions between own course of action and those of the enemy and the comparison of advantages and disadvantages of each alternative course of action. The estimate lends itself to a matrix display, listing alternatives to own course of action down the side and alternative enemy courses of action across the top.

5 - COMMINICATIONS

In an information flow sense, the world has become smaller as modern telecommunications has made it possible for people in their living rooms to view in full color an event anywhere around the world. The physical separation of decision makers from each other and from the facts on which they should rely to make their decision is being overcome by modern telecommunications. The rate of change of events is usually greatest at the scene of action, while the opportunity to readjust decisions is distributed throughout the chain of command.

To understand the telecommunications process it is necessary to appreciate two of its aspects: It is symmetrical and it is arbitrary. As ideas move from the mind of one commander to the mind of another, the transformations that are undertaken on the sending (transmitting) side have to be matched on the receiving side, and they have to be matched exactly. Everything that is done must be undone; every analog-to-digital conversion needs to be matched by corresponding digital-to-analog conversion at the other end, every encryption by a decryption and every modulation by a demodulation. Therefore, the planning necessary to achieve an effective telecommunications path is detailed and unforgiving: any unmatched step will result in communications failure. It should be clear then, that with all the alternative methods available for performing each of the communications steps, the dominant issue in establishing a telecommunications path is not its optimization but the standardization of its process at each end. More important than doing things the best way is doing them the same way which is the objective of the program on joint interoperability of tactical command and control systems. Historically, the telephone network with its analog transmission system was well matched to its information source; the human voice in analog form. The transmission of teletype and increasingly, computer data required that the digital information be converted prior to transmission over the telephone network into some analog form by the use of a modular, whose functions were matched in reverse at the receiving end by a demodulator. These modulators/demodulators (now generally called "modems") provided the conversion from one form to the other.

6 - COMPUTERS

The role of computers in support of command and control is still evolving. Apart from their extensive use in sensor and communications networks and in the correlation, filtering, and analysis of information about the enemy, computers are used to support the command and control process in three ways:

1. To maintain the status of own forces.
2. To optimize deployment plans and test them for transportation feasibility.
3. To assist in predicting outcomes of military engagements.

There is now considerable experience using computers to maintain the status and to some extent the location of some forces, but whether the tremendous reporting and computing effort has been indeed useful to decision makers is not really clear. Commanders exercise their authority over commanders at the next lower echelon. It is possible for the information to have been reported incorrectly or to have changed since the latest report was written. Reports are more likely to be accurate when the reporting system has been devised in a way that provides some incentives for reporting commands to make accurate and timely reports, an aspect of reporting system design sometimes over looked. An alternative method of obtaining accurate (though not necessarily relevant) information in reports is to directly couple the sensor or weapons system that measures or produces the raw information with some automatic reporting device, but this method is usually not popular with intervening commanders.

The optimization and testing of deployment plans is a role for computers that has received great emphasis in recent years and with some success. The prediction of outcomes of military actions---the role often envisioned for commanders seem to be most useful where physical parameters dominate, and perhaps where human conduct can be presumed to follow rigid doctrine. The two sided nature of combat and the wide variability of human responses, however, make the prediction of outcomes of military action by any means very difficult.

CHAPTER VI

1 - CONCLUSION

There are two recent developments that seem already to be changing the face of air defence, indeed of air combat as a whole, first there is "stealth." It is clear that the USAF intends to build and deploy a wide range of stealthy air vehicles both fighters and bombers. (The Lockheed F-117 and the Northrope B-2) appear to be designed as intruders rather than for air defence purposes. But what is now obvious is that very low radar cross section (RCS) are achievable and affordable. Reductions in RCS are the basis of achieving low observability and the effect can be calculated quite simply because all radars conform to an immutable law of physics that detection range varies with the fourth root of RCS measured in square units. That means if the RCS is reduced by a factor of 10 then the detection range should be divided by 1.78 thus if an aircraft with an RCS of 10 Meters Squared (M2) could be detected at 100nm range then a reduction of Im2 RCS will result in a pick-up range of 56n.m. Now looking at the possibility of RCS in the head on situation of 0.01 m2, the prospects for detection begins to look very bleak, particularly for SAM systems which we know rely to a large extent on radar direction to achieve a kill. Al radars will be affected in the same way. For the cruise and ARM missile, ultra low observability seems now to be within the grasp of most nations with a high technology industrial base, and long range air-to-surface missiles released at a reasonably long range can swamp the defences.

Apart from stealth, one other area that seem to offer clear potential for advances is that of the airborne sensor systems themselves. Until a radar is devised that can detect the low RCS target at reasonable range, the air defence fighter will have to rely on alternatives. Infrared search and track (IRST) appears to offer some prospects for success. IRST has its problems too. It needs clear air mass conditions (no clouds) to be effective, it is at its best at the higher altitudes, away from the effects of ground heat and it is extremely difficult to get anything other than a very coarse estimate of range. Nevertheless, when combined with other information that may be available to the crew, IRST might be able to get the fighter close enough to its target. Thus one can see a murky world of stealth and counter-stealth emerging with each of the protagonists attempting to outwit the other in a game where the first one to transmit any signal maybe the loser. And finally, whatever the real advances turn out to be, one thing is certain, as long as there are nation states which value their citizens and their right to decide their own future, the need will remain for modern highly integrated air defence systems capable of providing defence against enemy attack.

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